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THE NEUTRON TOTAL CROSS SECTION OF SINGLE CRYSTAL SILICON AT 21°K

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The neutron total cross section of a single crystal of Si has been studied over the energy range 0.003 eV to 50 eV at the Weapons Neutron Research Facility (WNR). The neutron energies were determined by time of flight. The 28.77 cm long Si sample was held at three temperatures, 296°K, 77°K, and 21°K. The 21°K temperature was obtained by filling an encircling cryostat with liquid H₂. The region of greatest interest is below 1 eV where Bragg scattering from the perfect crystal is small and where thermal diffuse scattering can be reduced by cooling the Si. Near 0.05 eV the cross section dips to less than 1/5 its value at energies greater than 1 eV. This feature has allowed single crystals of Si to be used very successfully as thermal neutron band pass filters. Our data at 296°K and 77°K agree with previous measurements. Very little structure caused by Bragg scattering is observed. Our measured cross sections for 21°K are somewhat below the 77°K data but not enough lower to justify cooling a Si filter to 21°K to dramatically improve its transmission.

[Si(nn), total cross section, 0.003 - 50 eV, single crystal, 2.96, 77, 21°K]

Introduction

Fission reactors are intense sources of thermal neutrons which are being used extensively for materials studies.¹ Unfortunately these thermal neutrons are accompanied by fast neutrons and gamma rays which produce a background in many experiments in addition to being a hazard to personnel. Filters are needed that will pass bands of thermal neutrons but reject the fast neutrons and gamma radiation. Some single crystals act as thermal neutron band pass filters and are being used.² Silicon has recently found application as such a filter.^{3,4,5} Presented in this paper are new total neutron cross section data which will allow experimenters to evaluate and to select the most effective parameters for the design of single crystal silicon filters.

Previous cross section measurements^{3,4} of single crystal silicon have been made at only a few neutron energies at room temperature (RT) or liquid nitrogen temperature (LNT). Data over a wider energy range with better resolution were needed for evaluation and design. The cross sections presented here provide that breadth and resolution.

One previous cross section point⁴ was obtained at 0.073 eV at liquid helium temperature (LHeT) but with some experimental uncertainty in the measurements. Since this one point indicated that a silicon filter cooled to near LHeT would be much more effective than one cooled to near LNT, more data near LHeT were needed. Such data are presented in this paper as the cross section of single crystal silicon at liquid nitrogen temperatures (LNT).

The experiment is described in the next two sections, the data in the fourth section, and the results are discussed in the final section.

Sample

The sample was one single crystal of silicon provided by the Electro Products Division of the Monsanto Company. This crystal is 7.6 cm diameter by 28.77 cm long. One of the symmetry directions of the crystal is along the axis of the cylinder. The crystal is dislocation free and was made by the Czochralski process.

This crystal was inserted into the center of an annulus formed by the liquid nitrogen (or liquid hydrogen) jacket of a cryostat. The ends of the annular hole were sealed with thin windows of stainless steel so that helium gas could be added to provide heat conduction from the crystal to the annular liquid hydrogen jacket. Thermocouples were attached to the crystal to measure the temperature.

Experiment

The Weapons Neutron Research (WNR)⁶ facility at the Los Alamos Scientific Laboratory (LASL) was used as the source of neutrons for the total cross section measurements. The WNR produced pulses of moderated neutrons using a 3 μ s wide 800 MeV proton pulse at 60 Hz incident on a tantalum target with a heterogeneously poisoned H₂O moderator. Cadmium was used as the poison in the moderator to suppress upscattering. An off-center flight path observed the "slab" geometry neutron moderator. The neutron energies were determined by time-of-flight methods. The experimental arrangement is shown in Fig. 1. A collimator with a 1 cm² hole was

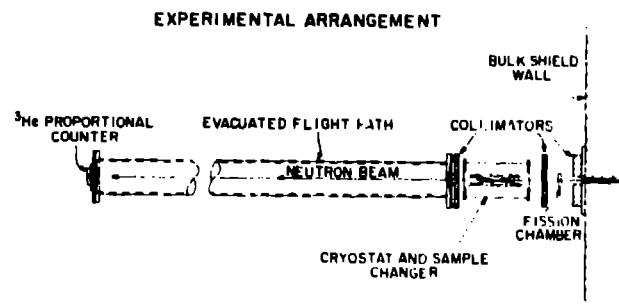


Fig. 1. Experimental arrangement of apparatus outside the bulk shield.

placed at the outer edge of the bulk shield, 3 meters from the moderator. A ^{235}U fission chamber was placed in the neutron beam after the first collimator to monitor the neutron flux. A second collimator was placed after the fission chamber to eliminate any effect of the sample position on the flux monitor. The silicon sample in the cryostat was placed on a remote control changer mechanism positioned about 25 cm from the first collimator. A third collimator was located downstream of the cryostat to ensure that the neutron detector viewed only the silicon sample and no part of the cryostat. The neutron detector was an 0.6 cm diam 300 Atm He proportional counter placed at 11 m from the moderator center at the end of an evacuated flight path.

The sample changer mechanism was a platform that could be raised and lowered so that data could be taken with the sample "in" and with the sample "out". The sample "out" position had two sheets of aluminum to simulate the windows on the cryostat. No correction was made for the difference in paths of vacuum, helium, and air.

Data were collected for repetitive sets of sample "in" and sample "out". Each "in" and "out" lasted about ten minutes to obtain good statistics. For the low temperature runs, thermocouples monitoring the sample temperature were read between each set of data. Room background was measured by placing either a 0.08 cm Cd sheet or a 5.6 cm thick boron loaded paraffin block in the beam. In each case, in the regions of interest, the backgrounds were negligible. The data were collected and stored on magnetic tape using a Modcomp IV computer via a CAMAC interface. Data reduction consisted of correcting both sample-in and sample-out spectra for dead-time losses, combining the data into bins of constant (10%) energy resolution, and converting to total cross section as a function of neutron energy.

Data

Figure 2 represents the data of this experiment. The data extend from 0.003 eV to 50 eV and cover the window which is important as a band pass filter. At 50 eV the scattering approaches free-atom scattering. Our measured cross sections at 50 eV are

$$\sigma_{\text{RT}} = 2.13 \pm 0.02 \text{ b},$$

$$\sigma_{\text{LNT}} = 2.11 \pm 0.02 \text{ b},$$

$$\text{and } \sigma_{\text{LHT}} = 2.10 \pm 0.04 \text{ b}.$$

These are in good agreement with the $\sigma_{\text{FA}} = 2.16 \text{ b}$ quoted by Willis. This agreement lends confidence that the cross sections are being measured accurately, for example; that the number of atoms/cm in the beam is known, that dead time corrections are being made correctly, and that backgrounds are understood.

At the low energy end of the data, the σ_{RT} appears to extrapolate to data extending up to 0.002 eV from BNL-325 for RT powdered Si. The σ_{LHT} and σ_{LNT} data approach but are slightly higher than the $1/v$ -line representing the absorption cross section of Si. This behavior is as expected and lends confidence that the cross sections are being accurately measured at the low energy end.

The data show the expected broad dip near thermal energies and the σ_{LNT} and σ_{LHT} cross sections are lower than the σ_{RT} cross section. Little structure is observed in the cross section indicating that Bragg scattering is small. These data at RT and LNT are consistent with the previous data. Our RT data for $E = 80.1 \text{ eV}$ is somewhat higher than data obtained by Shull.

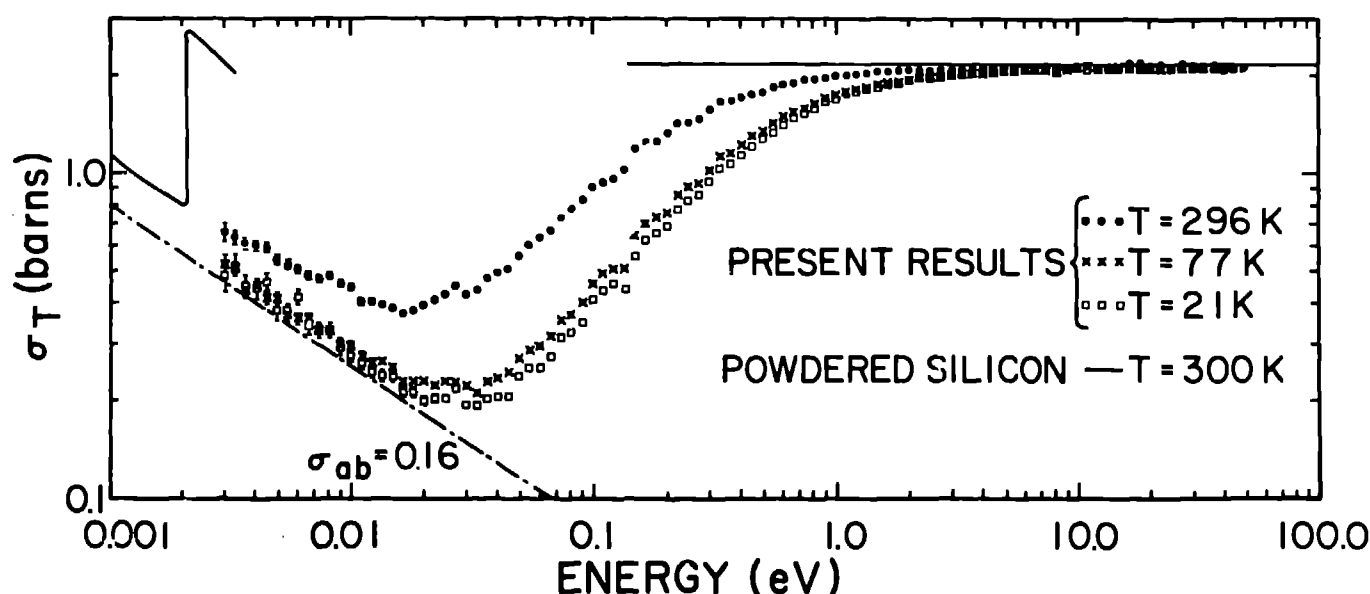


Fig. 2. Results of the present experiment. The solid lines represent data for powdered silicon. The dashed line shows the $1/v$ silicon absorption cross section.

The LHT data in Fig. 2 is not consistent with the previous cross section point measured by Brugger and Yelon⁴ at 0.073 eV and LHeT. While the present data shows a cross section of about 0.25b, the previous point was 0.1 b. The previous point is described as "not of high accuracy" because the sample was only 5 cm across and the sample could not be cycled into and out of the beam to get "in" and "out" data. A change in the beam intensity during the experiment could have produced a poor measurement.

Conclusions

The cross sections measured in this experiment provide high resolution data over the full range of neutron energies needed to evaluate silicon single crystal band pass filters. The RT and LNT data agree with previous measurements. Little structure is evident. The cross sections at LHT are only slightly lower than the cross sections at LNT. Thus a silicon single crystal cooled to LHT or LHeT will be only a little better as a filter than one cooled to LNT. The extra effort to cool below LNT is not justified.

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